The control of Multi-Agent Systems (MAS)

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Abstract

Doubt continues that current theories and practices can produce agent or multi-agent system (MAS) autonomy (Pynadath et al., 2001), imperiling future MAS missions (Lawless & Grayson, 2004). One possible reason is that from the view of "methodological individualism" (Nowak & Sigmund, 2004), reality is a stable phenomenon meaning that a single best view of reality is mathematically possible, a thesis that Benardete (2002) rejects. Alternatively, social reality is bistable (bistability occurs when a phenomena exists in one of two interdependent states; e.g., bistable interpretations refer to two stable, incommensurable interpretations of one data set, illustration, or phenomenon), and is best modeled by the quantum relations (Bohr, 1955). Given multiple interpretations of the same context or situation, to control an MAS, a group or decision maker can choose to avoid multiple interpretations as advised by Nash (1950) in order to converge mathematically to a consensus which we conclude is optimal to enact solutions for well-defined problems (*wpd*'s), or to exploit these multiple interpretations which we conclude is the only way to solve ill-defined problems (*idp*'s) (Lawless & Grayson, 2004).

Introduction

To construct a mathematical theory of organization for the control of MAS's sufficient to generate agent autonomy, we utilize several theories, each of which has been insufficient to date. We begin with the disputed (Christensen & Walczynski, 1997) complementarity theory of long-term intimate, business, or social relationships known colloquially as "hand and glove" or "lock and key" relationships. We account for the failure of complementarity with the widespread recognition that the methodology of survey questionnaires to study group dynamics, having run aground theoretically (Levine & Moreland, 1998), has never been able to rationally distinguish an arbitrary sum of "individuals" from the "members" of an organization (Luce & Raiffa, 1967). To this recognition we add Kelley's (1992) failure with exchange (game) theory to map one-to-one between strongly stated preferences and the results from given matrices such as the Prisoner's Dilemma Game; add the lack of theory to account for individual self-reports from those under social influence (SI), such as Milgram's (1974) obedience to authority, or Asch's (1951) line judgment in the presence of dissenting others; and add the inability of even perfect interviews to reconstruct an interaction without a convergence aligned with the meaning structures of the interviewers (Eagly & Chaiken, 1993; e.g., as indirect support, there is a clear ideological divide in the decisions of judges appointed by Republican and Democratic Presidents; in Sunstein et al., 2003). We create a functioning theory of organizations to control an MAS from these theories by accounting for the uncertainty in states as agents shift during an interaction between the "individual" state into the organization "member" state, this bistable shift being one of the oldest, unsolved problems in social psychology (Allport, 1967).

Survey Questions

There are multiple problems with survey questions. They provide static information about dynamic processes (Lawless et al., 2000a). The very act of asking has an observable effect (Carley, 2003), at the very least shifting respondents from a group

state to an "individual" state in order to respond. And Eagly and Chaiken (1993) concluded that survey questions can be worded to produce any desired effect. As an example of the problem that this may cause, a study of risk perception by Slovik and colleagues in 1991 with questionnaires led to their prediction that the negative images associated with a nuclear waste repository at Yucca Mountain would harm the Las Vegas economy by reducing tourism; however, ten years later Slovik admitted that tourism continued to make Las Vegas the fastest growing community in the U.S (Slovik et al., 2001, pp. 102-3).

Part of the problem with surveys reprises Nash's (1950) observation that nothing can be said mathematically when the two sides to a negotiation are polarized. Polarization is all too common but its function as a bistable phenomenon is hard to explain, yet it is the central feature of democracy (Benardete, 2002). For example, a survey of Republicans who saw the film "Primary Colors" believed that it accurately portrayed the Clinton Presidency while Democrats disagreed (Lawless & Schwartz, 2002). A survey by Hart (www.pollingreport.com) found that while Democrats believed that CNN provided accurate news, Republicans disagreed; and while Republicans believed that Fox News is accurate, Democrats disagreed. These competitive interpretations were called "social histories" by Schama (1995). Van Eeten (2002) described the negative aspects of polarization as "dialogues of the deaf", and the media is often blamed as the cause (Sunstein, 2001). However, we regard these bistable phenomena as the driving force to social, scientific, and technological evolution (Lawless & Grayson, 2004); e.g., Kuhn (1977) concluded that polarization was the essential tension that preceded scientific progress.

Exchange (game) theory

Symbols in game theory are accepted as fully objective and stable reflections of independent states in human minds; however, any mathematical scheme represents the "phenomena so far as the correspondence between the symbols and measurement goes" (Heisenberg, 1958, p. 172). Thus, the consistent mathematical schemes using artificial agents to solve game matrices locate concepts precisely but without mapping into social reality, partly because agents are not social yet, but consequently becoming a normative projection of values instead of a tool to solve interaction problems (Gmytrasiewicz, 2002). Partly this is because artificial agents are not socially influenced by the presence of others as are humans, and partly the normative value of "cooperation" can only be implemented with coercion from social influence (SI) (Axelrod, 1984; Hardin, 1968). To make game theory more objective requires a functional approach to cooperation, partially achieved with the introduction of entanglement in quantum game theory (QGT; Eisert et al., 1999), although QGT falls short by retaining normative solutions.

A new theory of games can be proposed with a model of mergers (Figure 1). As part of attacks by businesses to control a market by defeating weaker opponents, competition produces winners and losers across a market, the losers either going bankrupt if they have little to offer, or being acquired by stronger firms if they retain value (e.g., Dell Computer's attacks against Hewlett-Packard and Compaq eventually led to their merger into H-P in 2002). Attacks organize battlefields, funding requests by charities, audience share between artists (e.g., Jay Leno versus Dave Letterman), political campaigns, and, among many others, proselytizing for church members. But instead of reducing social welfare as currently envisioned in traditional game theory (Nowak &

Sigmund, 2004), attacks are fundamental to self-organization processes, especially among citizens, scientists, politicians, entertainers, or any group attempting to solve an *idp*. For example, despite a head start and extraordinary public financing given to the consensus-seeking Human Genome Project by the National Institutes of Health (NIH), the private startup, Celera, raced ahead to decode the human genome first, winning patents and rich fees, forcing the NIH research team to play catch-up. Compared to NIH's "free" product, Celera's was more complete, had fewer mistakes, and has saved scientists considerable effort in their discovery of new products; afterwards, NIH became a client of Celera (Lawless, 2001).

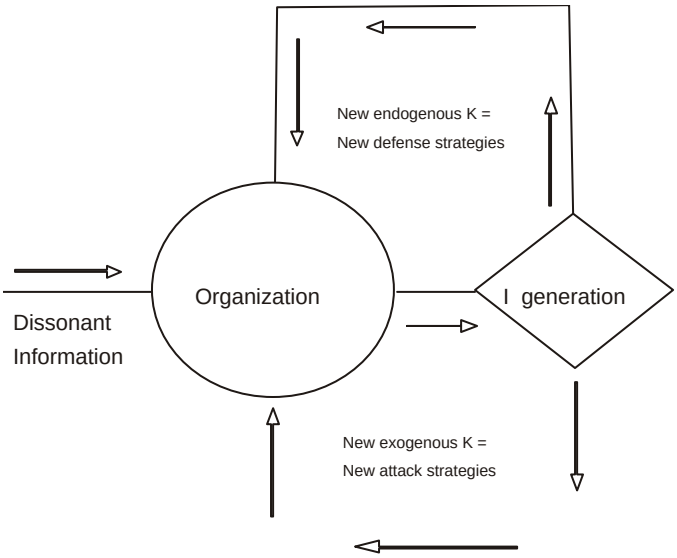

Fig. 1. Perturbations generate endogenous and exogenous I.

After a perturbation (Figure 1), an organization generates endogenous feedback to dissonant information, *I*, by creating new knowledge, *K*, to design new innovations, merger strategies or technology to better defend itself (e.g., the 2003 Air France-KLM merger to better compete with European low-cost carriers). As a function of its application, this *K* is known as a business model, worldview, scientific model, or medical model. Conversely, with exogenous feedback, a competitor devises innovations, strategies or technologies to defeat the organization (an exception is when two competitors choose to collude). In general, the quicker respondent determines which organization wins and evolves (Chagnon, 1988; i.e., in engineering control theory late feedback is destabilizing; in May, 2001, p. 5); e.g., in 2003 in the war with Iraq, coalition decision-making and implementation of those decisions occurred faster than Iraq's Defense Forces, causing the latter to panic (from Lawless & Grayson, 2004).

Instead of the usual game matrix overvaluing cooperation, we propose a tensor as a variant of game theory and the community matrix (May, 2001). This change has the initial advantage of retaining the basic structure of traditional games, such as the Prisoner's Dilemma Game, where mutual competition reduces joint payoffs and mutual cooperation increases joint payoffs. However (see Figure 2), the primary difference is that mutual competition increases social welfare while mutual cooperation decreases it;

e.g., discount airlines have reduced the average costs to about 6 cents per passenger seat-mile flown versus 10 cents per seat-mile for the major airlines, with U.S. Airways charging about 17 cents per mile on its highest rate route before its bankruptcy.

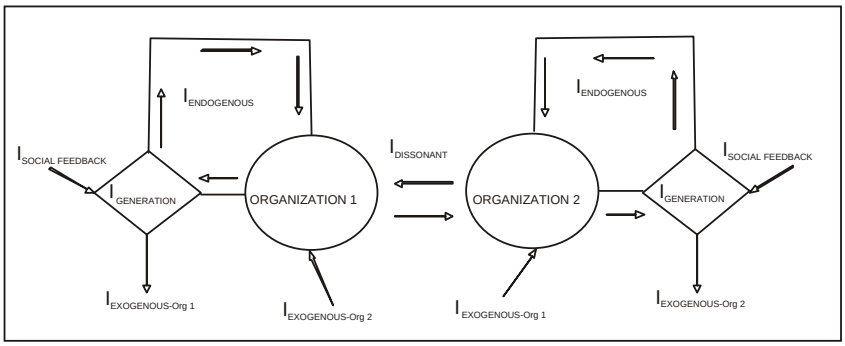

Fig. 2. A revised model of game and quantum game theory (Lawless & Grayson, 2004).

In Figure 2, the interdependent flow of dissonant *I* between Organizations 1 and 2 produces observational uncertainties *(•I*) of competitors (e.g., faulty communication, misunderstanding, deception, bluffing, or illusion). Perfect resolution implies *K*, whether by duplicitous (e.g., Department of Justice charges in 2003 against Boeing www.usdoj.gov:80/criminal/cybercrime/branchCharge.htm) or normal means (e.g., price signals, price leadership, forum exchanges, court challenges, patents, financial disclosures, market analyses). But *K* obtained by driving *•I* to zero has limits. Per Lewin (1951), how an organization behaves must also be determined (i.e., *•a*, for action uncertainty). Specifically, an interdependence exists between *•a* and *•I* that limits the *K* produced (i.e., from the two equations, $\bullet a \bullet I \bullet c \bullet \bullet E \bullet t$, where *•E* is energy uncertainty and *•t* is time uncertainty; see Figure 3) indicating that organization inertia, *J*, is a key factor in strategy and adaptability to perturbations). As an example, Robert Hutchings, Chair, National Intelligence Council (www.cia.gov/nic/speeches), noted that an underestimate by the National Intelligence Estimate of Iraq weapons for the 1991 war may have led to overestimates in the 2003 war. This illustration also accounts for the mergers that arise from perturbations: Should an organization's execution of technology falter, as in the case of AT&T Wireless in early 2004, it becomes the prey or acquired organization instead of the predator. Unlike game and quantum game theory, power accrues to the winning organization and its chief strategist; e.g., in 2003, Southwest Airlines had twice the value of all six U.S. airlines larger than it combined (ATA, 2002). Finally, from this figure, while social feedback occurs when neutral members of the public form a superposition on an organizational problem sufficient to randomly explore the space of possible alternative solutions (e.g., the choice of budget airlines or major airlines, such as Southwest or Delta), social feedback has similar uncertainty limitations, motivating the reduction of action and observation uncertainties with perturbations (e.g., to reduce the social uncertainty in their respective fields, politicians, movie producers, and nuclear waste decision makers with the Savannah River Site Citizens Advisory Board often use focus groups to search for possible solutions to *idp*'s).

Social Influence

The interaction transmits social influence (SI). SI causes a mental rotation to reduce *I* under forcible conformity, or increase information with dissensus between two opposed agents or organizations witnessed by neutral observers (Lawless & Schwartz, 2002). In anticipation, observation affects social phenomena (Carley, 2003; Lipschitz, 1997; Heisenberg, 1958, p. 173), causing the problems with game theory noted by Kelley. SI can be transmitted directly to cause obedience from authority figures (Milgram, 1974; Asch, 1958), making it easier for totalitarian regimes to coerce cooperation while seeking consensus, dampening self-organization processes. This is the reason that less scientific wealth, poorer health, and more corruption occur under consensus government (Lawless et al., 2000b); in contrast, the freedom in democracies to experiment permits a wide-ranging random search for solutions to problems of all sorts, including novels, politics, and technology, solutions when supported by society (stochastic resonance) that power its evolution (Lawless & Grayson, 2004).

Different contexts can affect how SI is transmitted in the interaction. For example, randomly created groups automatically produce in-groups and out-groups (Tajfel, 1970). Ball and Eckel (1998) have randomly assigned artificial status to players in traditional games, affecting how they play the games. And compared to democracies, consensus decision making or command economies suppress self-organizational processes (Janis, 1984; Lawless & Schwartz, 2002; Milgram, 1974).

Interviews

Post-modernists argue that giving voice to all citizens by forcibly seeking a consensus single view of philosophy, vision, and values under cooperative ("good") relationships improves social welfare more effectively than the competitive ("bad") relationships traditionally found in democracy among the multiple interpretations used to decide issues with common sense and scientific evidence. For example, DOE-Environmental Management's policy for its Citizen Site Specific Advisory Boards encourages its Boards "to work toward consensus" in order to be "fair" (www.em.doe.gov/public/ssab). However, armed with only their subjective interpretations of interviews for evidence, the recent DOE Evaluation Team (a subcontractor to DOE) justified DOE's promulgation of consensus decision-making as an improvement in the majority-rule decision-making used in democracy (Bradbury et al., 2003). But although the team leader described the Citizen Boards across the DOE complex as a "grand field experiment", no empirical evidence was collected from the field by the DOE Evaluation Team to validate its belief that consensus produces more effective and fairer decisions. Nor is there field data to indicate that consensus decisions accelerate the cleanup of DOE sites. In contrast, experimental evidence in the social science literature (e.g., Janis, 1982) and available field data (Lawless, 2004) contradict DOE's policy on consensus decision-making: consensus seeking retards the cleanup; the cooperative ("good") relationships necessary for consensus require coercion, reducing trust; and the competition of ideas driven by majority-rule improves decisions.

The data indicate that there is no problem with arriving at consensus as long as the decision process is competitive; problems arise by forcibly seeking consensus as in the DOE policy. As is, without first using scientific validation, DOE's policy of consensus-seeking serves to promote antiscientific views, misperceptions of risk, and an uneducated citizenry regarding its nuclear mission and the DOE cleanup.

Complementarity

The disaggregation shift from organization "member" to "individual" in response to survey questions can occur rapidly, implying that the term "individual" in itself is meaningless. We assume that this bistable shift between stable states is accompanied with measurable increase in energy, *E*, as an agent moves from its ground "preferred" state in the organization to its first level of arousal (from House et al., 1988). By extension, executing the solution to a *wdp* occurs at a social, organization, or system ground state; in contrast, solving an *idp* occurs at an excited state (Lawless & Grayson, 2004).

Regarding uncertainty in the social interaction, Heisenberg wrote "We realize that the set of complementarity is not confined to the atomic world alone; we meet it when we reflect about a decision and the motives for our decision or when we have a choice between enjoying music and analyzing its structure" (Heisenberg, 1958, p. 179). Similarly, Gibson (1986) concluded that humans can view either the aesthetics of art or its construction. Caccioppo and his colleagues (1996) established physiologically that subjects can view one aspect of an illusion at a time (all illusions are formed from bistable pictures; i.e., a bistable picture is a two-dimensional picture that has two stable states or two incommensurable interpretations, both equally justified by the available data), but not both simultaneously, such as the famous faces-vase illusion, leading to the expectation that blood flow in the brain is lower (less cost or *E*) in the ground state than in an excited state.

From the perspective of traditional logic (Tessier et al., 2000), either an agent is in an "individual" state or "member" state, but not both (however, Aristotle's axiom of the excluded middle has been revised for intuitional logic but retains most standard axioms with appropriate revisions). In quantum logic, this bizarre state of being in both states simultaneously can occur (Rieffel & Polak, 2000). We hypothesize that an agent can be either an "individual", a "member" of an organization, or in both states simultaneously. But having an agent in two states at once defies intuition, explanation and meaning. Accepting that this can occur agrees with Feynman's (1967) observation that while an understanding of quantum states is not possible, its mathematics can be used productively. In the situation where two opponents are in dissensus before a neutral audience of judges, the judges are in the bizarre state of superposition or low information. Measuring them generates classical information.

To track the probability of locating an agent in one or both of these states, the absolute square of the complex number gives its probability, the sum of the two probabilities referring to the two states being unity. Complex numbers allow us to represent this shift as a mental "rotation" in a given game matrix or physical state as the interactants "adjust" their perceptions to shift a concept's meaning (for a review of "rotations" applied to weather forecasting, see Trafton & Hoffman, in press). Whether an agent is "individual" or "member" or both is undecided until a measurement is made, the measurement shifting the agent definitively into one state or the other with probability 1, but at the same time breaking the one-to-one correspondence with the other state, the central cause of the failure of language to fully capture social reality (Bohr, 1955). In essence, disturbing two agents in their highest state of cooperation breaks it apart, as when they are interviewed, thereby generating classical information—no information other than classical information can be generated. However, at the same time, summing this classical information does not reproduce the group (Levine & Moreland, 1998) forming the measurement problem (Figure 3).

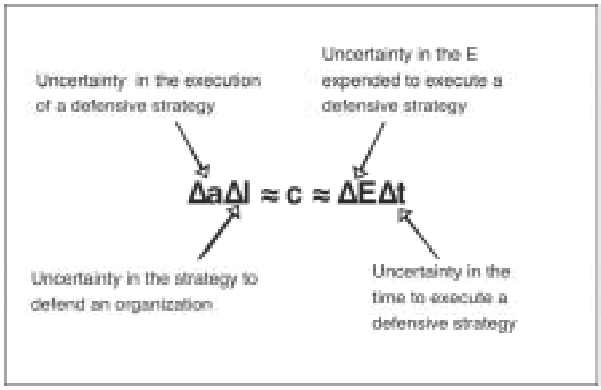

Fig. 3. The measurement problem.

The measurement problem in Figure 3 is portrayed for the business model versus its execution, shown here from the perspective of a merger target (parallel uncertainty relations exist for the acquiring organization). Measuring an interdependent or bistable phenomenon such as a human organization produces classical *I* that cannot recreate the original phenomenon. For example, **Strategy**: after AT&T Wireless put itself on the auction block and Cingular made the first offer, AT&T Wireless did not know whether bids would be received from other players such as Vodaphone, or how much more would be offered; **Execution**: Cingular expected that AT&T Wireless would execute its strategy by choosing the best bid by the deadline it had set, an expectation that turned out to be incorrect; ***E* of Acquisition**: AT&T Wireless did not know whether Cingular or Vodaphone would increase their bids to an amount it considered sufficient; **Cycle Period**: while the bidders believed incorrectly that the deadline was firmly established, AT&T Wireless was uncertain of the time between the bids that would be offered. Finally, although power goes to the winner, it is not easy to determine who won and who lost in this auction. AT&T Wireless was unable to enact number portability and became the prey, but its CEO exacted a superior premium for his company and stockholders; while the merger on paper makes Cingular the number one wireless company in the U.S. today, it may have overpaid for the merger; and during the uncertainty of regulatory review (both the length of the regulatory review period and the regulatory decision), with AT&T Wireless already losing customers as competitors exploit the regulatory uncertainty, it is unknown how costly the eventual merger will be based on the assets remaining once the merger has been consummated. However, consolidation mergers, as in the steel industry in 2004, can reduce social welfare when an oligopoly and higher prices result.

Adjustments (social information processing and decision making) are the natural process of rotating worldviews either into opposition to generate new *I*, or into consensus to reduce *I* into *K* (e.g., dictatorships or totalitarian governments use SI to forge consensus). Adjustments find the best available solution to an *idp* given the limited worldview of participants (Simon's bounded rationality) or to a single consensus worldview of a group (totalitarian) such as the normative beliefs underlying traditional game theory or religion. These adjustments lead to more or less self-organization.

Organization theory

Mindful that the rotations between belief *K* (e.g., business models) versus the skills to enact them are conjugate (Figure 3), we sketch our preliminary ideas for the adaptability of belief models for organizations. Given adaptation, *A*, equal to knowledge, *K*, times competitiveness, C (i.e., $A = K \bullet C$; with *C* from Glaeser, 1996, equals the number of firms, #F, divided by the number, *N*, employed by these firms, so that $C = \#F/N$; also, Glaser use the years of education as an indirect measure of *K*), applying the derivative to *A* gives approximately the adaptability or the change in adaptation (also the change rate, or *dA/dt*; we crudely set inertia $J = K/Volume \bullet K/N$, where *N* represents those in the volume of an organization):

$$\bullet A = \bullet(K \bullet C) = C \bullet\bullet K + K \bullet\bullet C \qquad (1)$$
$$= \#F/N \bullet N \bullet J + K\,[N \bullet \#F - \#F \bullet N]/N^2 = [JN \bullet \#F - J\#F \bullet N + FN \bullet J] / N$$
$$\bullet A = J \bullet \#F - JC \bullet N + \#F \bullet J$$
$$= [\text{average Education}\bullet\bullet(\#F)] - [\text{ave Ed} \bullet C \bullet\bullet (\text{growth})] + [\#F \bullet\bullet (\text{ave Ed})]$$

To gain a rough idea of the value of Equation (1), we explore its application in Table 1 below, where the result indicates an approximate fit with known data.

Table 1: The game theory tensor of *K* (i.e., business model) and organizational adaptability. Applying the three factors of Equation (1) separately to the broad economic history of three areas over the past decade illustrates Equation (1) across these three dimensions (i.e., change in the number of firms; change in the growth of the employed; and change in the average level of education). The result generally agrees with economic reports about these countries (AHDR, 2002; Lawless et al., 2000b).

Country	1st Factor	2nd Factor	3rd Factor	Result
Japan	0	+	+	0
Arab Middle East	0	+	0	--
USA	+	+	+	+

Organizations form around the teamwork associated with the solution of a well-defined problem (*wdp*, or *K*), such as the production of weapons (Ambrose, 2001), the delivery of services (such as religion, medicine, or entertainment), or, among others, the aggregation of political influence. When freely permitted, self-organized groups become organizations that promote a tendency for cooperation as the primary means of internal SI, but it is coercive, decision-making tends to be totalitarian and slaved to their business model, and other groups are considered stereotypically as threats (Tajfel, 1970). Generally, under cooperation, old information, *I*, to solve *wdp*'s has been converted into *K* (business model), while new *I* is reduced (Lawless & Grayson, 2004).

Adaptive artificial agents are representations of organisms derived from simple learning mechanisms, primarily reinforcement and punishment (Skinner's operant conditioning), that determine an agent's fitness. An MAS arising from these simple-minded, reactive artificial agents form complex but inaccurate combinatorial patterns of the ill-defined scenarios and options faced by social organizations, inaccurate because they are unable to validate the most simple behaviors or beliefs of organizations. These agent-based models (ABM's) find value in their capability of combinatorial review of scenarios and options for human observers, but no value as predictive tools (Bankes,

2002). More accurate human representations will not reduce this capability, and like weather prediction (Palmer, 2000), should lead to a more predictive and usable tool.

An organization will only survive if it produces more *E* than it consumes (i.e., it must generate more income than costs; in Coase, 1937). This closely follows the principle of least action, that is, of all of the paths open to an organization, the easiest one to follow costs the least, for example, solving *wdp*'s versus *idp*'s. However, solving *wdp*'s has a hidden cost in that organizing solely around the solution of a *wdp* over time increasingly resists change in response to new *I*, reflecting an inertia, *J* (Lawless et al., 2000b), that reduces the organization's ability to defend itself against attack. Our thinking is that an organization begins with a business model and retains it as long as the organization is growing and profitable (e.g., Microsoft rejected Comcast's request to join in its hostile attempt to merge with Disney), regardless of how well the model actually corresponds with reality; the model is changed, however, whenever the business is suffering or failing (e.g., the stock market in early 2004 is expecting that US Airways will re-enter bankruptcy again) or the market is changing rapidly (G.E.'s adjusted its business model in 2004 to expand into solar power by acquiring the largest American owned maker of solar equipment, AstroPower).

System theory and control

Systems organize around the solution to *idp*'s, such as science, the law, or legislation. In a system, decision-making is usually competitive, generating new *I*. The more uncertainty, the more effort experienced or time that it takes to process *I* in the search to resolve or find a solution to a problem (e.g., in the stock market, uncertainty results in sideways movement or in a sell-off; Insana, 2001). For example, early or later market futures priced to estimate the date of war in Iraq respectively either declined precipitously or rose in value as the actual date of war approached (Leigh et al., 2003).

In contrast to consensus or command decision making, if feedback of the results from the solution enacted to solve an *idp* is fed back into the democratic decision process, control in a system becomes a limit cycle (Fig. 4). The key to this occurring is to have polarized views (bistability) as drivers along with neutral observers as judges to moderate and control the polarization process (Kirk, 2003).

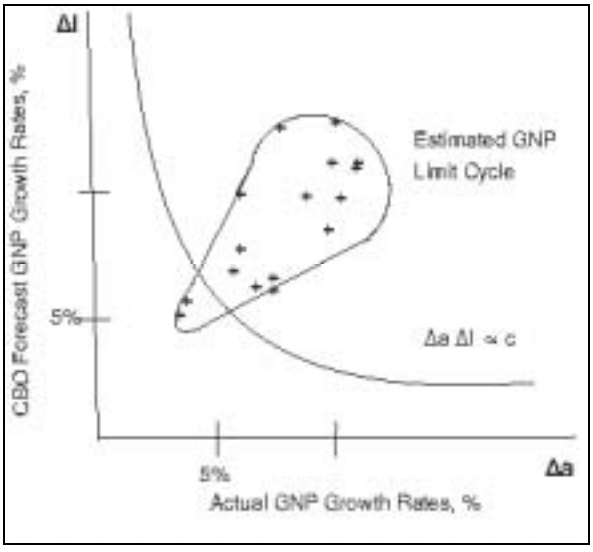

Fig. 4. Comparison of CBO forecasts of two-year average growth rates for nominal GNP output for the USA, years 1976 to 1992 (in 1992, CBO switched to GDP). The estimated limit cycle is for GNP data; it contracts as it moves towards the origin (increasing predictability), and expands moving away from the origin (increasing choice). For the curve $\bullet a \bullet I \bullet c$, with $\bullet a$ for action uncertainty and $\bullet I$ for information uncertainty, the value for the constant c has been arbitrarily chosen (from Lawless & Grayson, 2004)

Figure 4 above suggests that the uncertainty relations applied to the human interaction must be modified to account for feedback. When humans see the effect of real world outcomes on their solutions of *idp*'s, feedback adjusts future decisions to produce a limit cycle (e.g., p. 90, May, 1973). This contrast suggests that agents struggle in their attempt to resolve uncertainty. Arguments (attacks) between two opponents attempt to convince neutral decision-makers who act as a barrier that must be overcome by the "winning" argument that withstands "all contestations" (Lawless & Schwartz, 2002). We conclude that limit cycles provide a research path forward that offers the opportunity of solving autonomy for multi-agent systems.

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